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NASA/JPL L AND C BAND SCATTEROMETERS (Jet
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A User's Manual for the NASA/JPL Synthetic Aperture Radar and the NASA/JPL L- and C-band Scatterometers

T. W. Thompson



June 1, 1983

NASA

National Aeronautics and
Space Administration

Jet Propulsion Laboratory
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The research described in this publication was carried out by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

ABSTRACT

The Jet Propulsion Laboratory (JPL) will operate airborne synthetic aperture radars and scatterometers with the goals of acquiring data to support shuttle imaging radars and support ongoing basic active microwave remote sensing research. The NASA/JPL aircraft synthetic aperture radar is an L-band system at the 25-cm wavelength and normally operates on the NASA/Ames Research Center (ARC) CV-990 research aircraft. In the mid-1980s this radar system will be upgraded to operate at both the L-band and C-band. The NASA/JPL aircraft scatterometers are two independent radar systems that operate at 6.3-cm and 18.8-cm wavelengths. They are normally flown on the NASA/ARC C-130 research aircraft. These radars will be operated on 10 data flights each year to provide data to NASA-approved users. Data flights in fiscal year 1984 will be devoted to Shuttle Imaging Radar-B (SIR-B) underflights. Standard data products for the synthetic aperture radars include both optical and digital images. Standard data products for the scatterometers include computer-compatible tapes (CCTs) with listings of radar cross sections (sigma-nought) versus angle of incidence. An overview of these radars and their operational procedures is provided by this user's manual.

ABBREVIATIONS AND ACRONYMS

A/C	aircraft
ARC	Ames Research Center, Moffett Field, California
C-130	Lockheed aircraft, Model C-130
CCT	computer-compatible tape
CW	continuous wave
CV-990	Convair aircraft, Model 990
dB	decibels
FY84	Fiscal Year 1984
GHz	gigahertz (10^9 Hz)
HDDR	high-density digital recorder
HDDT	high-density digital tape
HH	transmit horizontal, receive horizontal polarization
HV	transmit horizontal, receive vertical polarization
Hz	hertz (cycles per second)
ips	inches per second
IRIG	Inter-Range Instrumentation Group
JPL	Jet Propulsion Laboratory, Pasadena, California
JSC	Johnson Space Center, Houston, Texas
kHz	kilohertz
km	kilometer
kts	knots (nautical miles per hour)
kW	kilowatt
MHz	megahertz (10^6 hertz)
μ s	microsecond

ABBREVIATIONS AND ACRONYMS (continued)

mm	millimeter
m/s	meters per second
NASA	National Aeronautics and Space Administration
nmi	nautical mile
ns	nanosecond
OSSA	Office of Space Science and Applications
pixel	picture element
pps	pulses per second
PRF	pulse repetition frequency
• RTOP	Research Technology Operating Plan
SAR	synthetic aperture radar
SCAT	scatterometer
SIR-B	Shuttle Imaging Radar-B
TWT	traveling wave tube
VH	transmit vertical, receive horizontal polarization
VV	transmit vertical, receive vertical polarization

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SECTION I

OVERVIEW

Over the past 15 years, the National Aeronautics and Space Administration (NASA) has developed several airborne radar instruments for remote sensing applications. Among these are an L-band synthetic aperture radar (SAR) developed by the Jet Propulsion Laboratory (JPL) and L-band/C-band scatterometers (SCATs) developed by the Johnson Space Center (JSC). In the 1980s these radars will be operated by JPL in a data acquisition program for NASA-approved users with two goals: (1) the acquisition of airborne radar data to support shuttle-borne imaging radars and (2) the acquisition of airborne radar data to support basic microwave remote sensing research. The specific objectives of this program are to provide SAR and SCAT data to users on an operational basis, to provide a mechanism for user feedback, and to help expand the application of radar data to a wider community.

For fiscal year 1984 (FY84), it is expected that this data acquisition program will be conducted in one combined CV-990 SAR/C-130 SCAT mission of three weeks' duration during August of 1984, when the Shuttle Imaging Radar will be in Earth orbit. There will be 10 CV-990 and 10 C-130 data flights. Following the flights, the SAR and SCAT data will be processed at JPL, with the objective of providing radar data for users within a few months after a mission's end. Following the receipt of their data, users will be expected to provide feedback to NASA on the quality and timeliness of their data.

In FY85 and beyond, it is expected that this program will be continued with one CV-990 SAR mission and one C-130 SCAT mission per year. Also, the NASA/JPL L-band SAR is being upgraded to operate simultaneously at L-band and C-band. It is expected that this dual-frequency SAR capability will be available in 1985.

Sections II and III of this report describe the SAR and SCAT radar systems; Section IV briefly describes some user duties. In addition, details of SAR and SCAT operations are given in Technical Data Sheets in the Appendix.

SECTION II

THE NASA/JPL L-BAND SAR SYSTEM

The NASA/JPL L-band SAR operates at a wavelength of 25 cm and at incidence angles of 0° to about 60° . It has polarization diversity and can simultaneously record HH, VV, HV, and VH modes with ground resolution of about 20 m. This radar is normally installed on the NASA/Ames Research Center (ARC) CV-990 research aircraft, a four-engine jet aircraft similar in range, speed, and size to the Douglas DC-8 and Boeing 707 commercial aircraft (see Figure 1). This aircraft is operated by ARC's Medium Altitude Missions Branch.

A block diagram for this radar is shown in Figure 2. Most of the radar electronics are housed in a radar box located in the CV-990 aft baggage compartment. This radar box includes a pulse generator and traveling wave tube (TWT) amplifiers which constitute a transmitter. Pulses are transmitted via a fan-beam antenna on the aircraft's starboard side. The fan-beam antenna on the aircraft's starboard side has a 18° degree beamwidth along track (i.e., parallel to the aircraft's velocity vector) and an 80° beamwidth in a plane perpendicular to the aircraft's velocity. Radar echoes from ground targets are received by the antennas, amplified, and heterodyned to video frequencies. These video signals are recorded on both optical and digital recorders. A control panel and desk-top computer located in the passenger compartment of the CV-990 aircraft are used to control the radar operation. SAR images are then produced by postflight optical and digital correlations. Table 1 gives a list of operating parameters. Details of the optical and digital recording modes are given in the Technical Data Sheets in the Appendix.

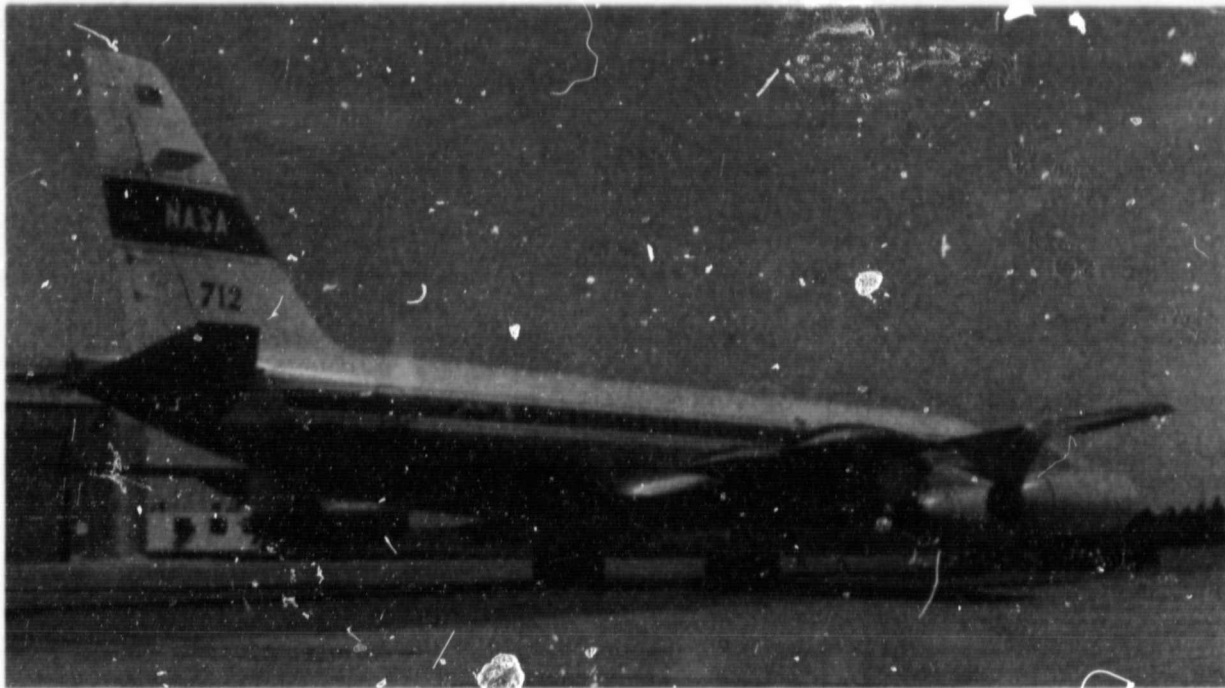


Figure 1. Galileo II, the NASA/ARC CV-990 Aircraft. This is a four-engine jet aircraft which has operating characteristics similar to the Douglas DC-8 and Boeing 707 commercial airliners. The L-band SAR antenna is mounted on a baggage door behind the wing on the aircraft's starboard side.

The operation of this radar depends upon aircraft altitude, speed, and flight duration. The CV-990 aircraft operates at 7 km (about 20,000 ft) to 13 km (about 40,000 ft) with ground speeds of about 200 to 250 m/s (about 400 to 500 kts). Optimum SAR operation is at about 8.5 km (about 26,000 ft) altitude. A normal flight lasts 4 to 6 hours, which permits 3 to 4 hours of SAR data acquisition. The NASA/JPL L-band SAR is first integrated into this aircraft and then used in a mission which will have 10 flights over a period of 3 weeks; one mission per year will be conducted. A SIR-B underflight program is planned in August 1984. A mission's first flight is usually dedicated to an engineering checkout of the radar, and the remaining flights of a mission may be dedicated to scientific data acquisition.

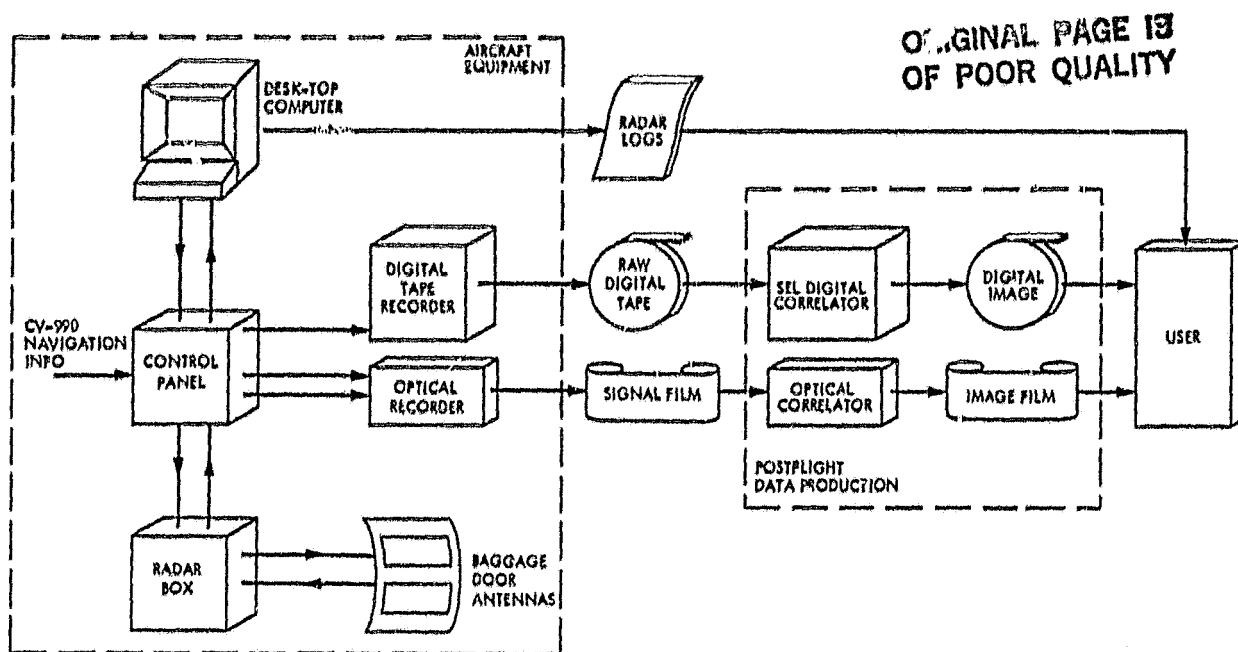


Figure 2. JPL Aircraft SAR System Overview. Aircraft operations acquire raw digital tapes and exposed signal film, which are processed to produce SAR images sometime after the aircraft flights.

During these missions, other nonradar instruments will be installed on the CV-990 aircraft. All instruments will be coordinated by a Mission Manager named by the ARC Medium Altitude Missions Branch. During the flights, the radar will be operated by JPL personnel. In all cases, a user or his designated alternates will participate in the flight operations. The user will be expected at Ames Research Center one or two days prior to the first flight of a mission and will be expected to stay with the aircraft for several days.

Following an aircraft mission, the radar data will be both optically and digitally processed at JPL. The optical correlator produces a strip image which has a format as shown in Figure 3. The normal optical correlator output is a 70mm film which is a few meters in length. This would be available to a user as film transparencies and strip contact prints.

Table 1. JPL L-band Radar Parameters

Parameter	Value
Radar frequency	1225 Mhz
Wavelength	24.6 cm
Pulse length	4.9 μ s
Bandwidth	18 Mhz
Peak power	6 kW
Antenna azimuth beamwidth	18°
Antenna range beamwidth	80°
Antenna beam center gain	12 dB
Nominal altitude	6.0 to 12.0 km
Nominal velocity	200 to 250 m/s (400 to 500 kts)
Nominal pulse repetition frequency	800 to 1000 pps or 1600 to 2000 pps
Noise equivalent sigma-nought	-45 dB
Number of looks	2 optical 8 digital
Dynamic range	12 dB optical 33 dB digital
Azimuth ambiguities	-20 dB optical -30 dB digital
Receiver noise figure	8 dB
Maximum receiver gain	97 dB
STC attenuation	20 dB
Receiver output	1 V peak-to-peak

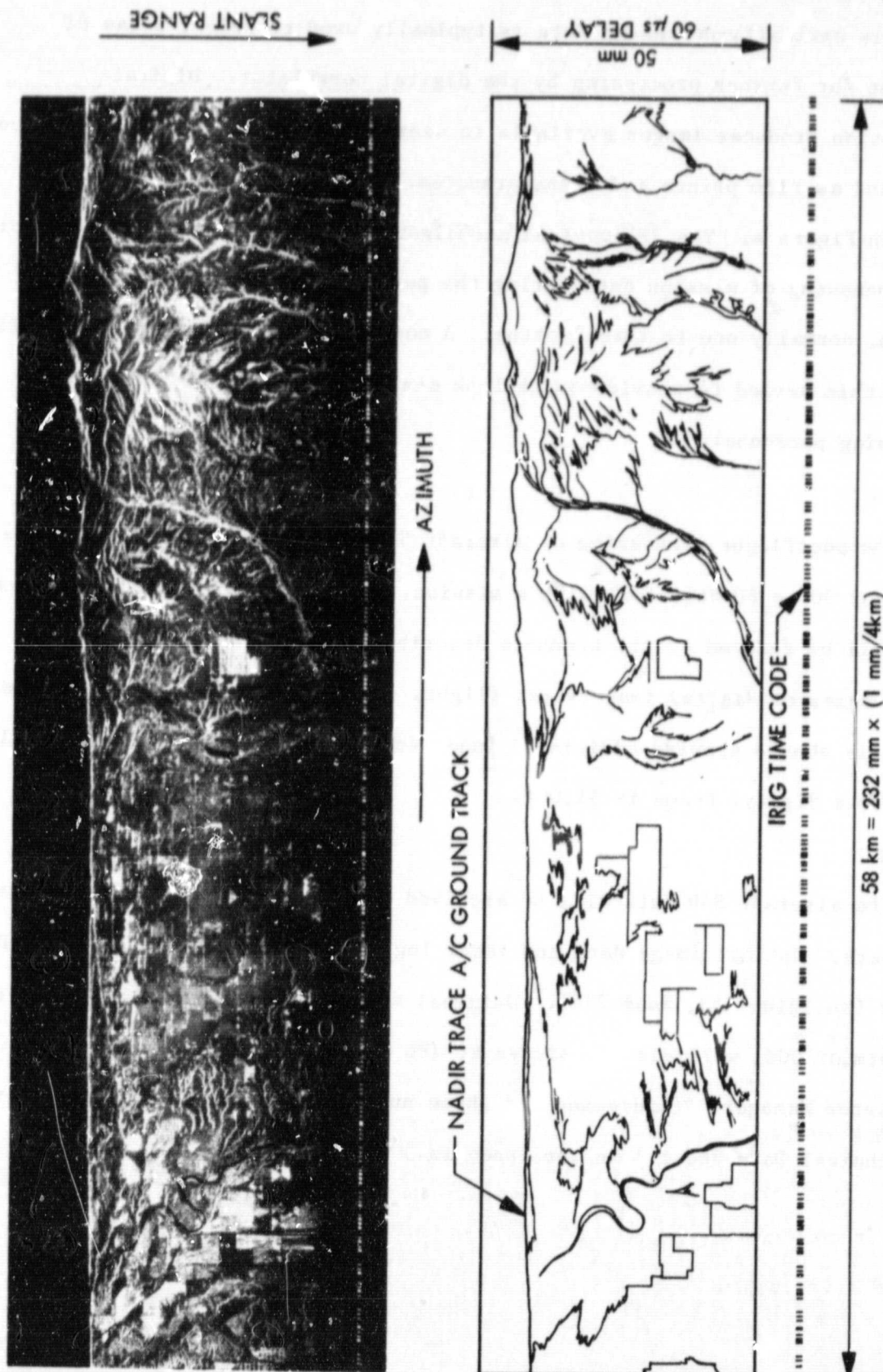


Figure 3. Optical SAR Image Format. Optical SAR images can be provided as film transparencies or as strip contact prints.

This optically-processed data is typically used to select areas of interest for further processing by the digital correlator. Digital correlation produces images available to users as a computer-compatible tape (CCT) and as film prints and transparencies. The digital image format is shown in Figure 4. The JPL optical and digital correlators will be used for the processing of mission data during the period immediately following a mission, normally one to three months. A non-JPL user may wish to be at JPL during this period to provide quick-look analysis and support to the processing personnel.

The postflight processing of aircraft SAR data will be conducted for a period of 30 to 60 days following a mission. It is expected that all optical data will be reduced to the products described above. There will be about three frames of digital imagery per flight. Users requiring more digital data than this should provide additional funds for data processing. The nominal cost for a digital frame is \$1,000.

The aircraft SAR data will be archived at JPL and will be available to all users. Optical image data and radar logs are stored in the JPL Radar Data Center (Building 183, Room 718). Original signal films, and digital data in the form of CCT, will also be stored at JPL under the control of the JPL Correlator Manager. (Addresses and phone numbers for JPL personnel are given in Technical Data Sheet 1 in the Appendix.)

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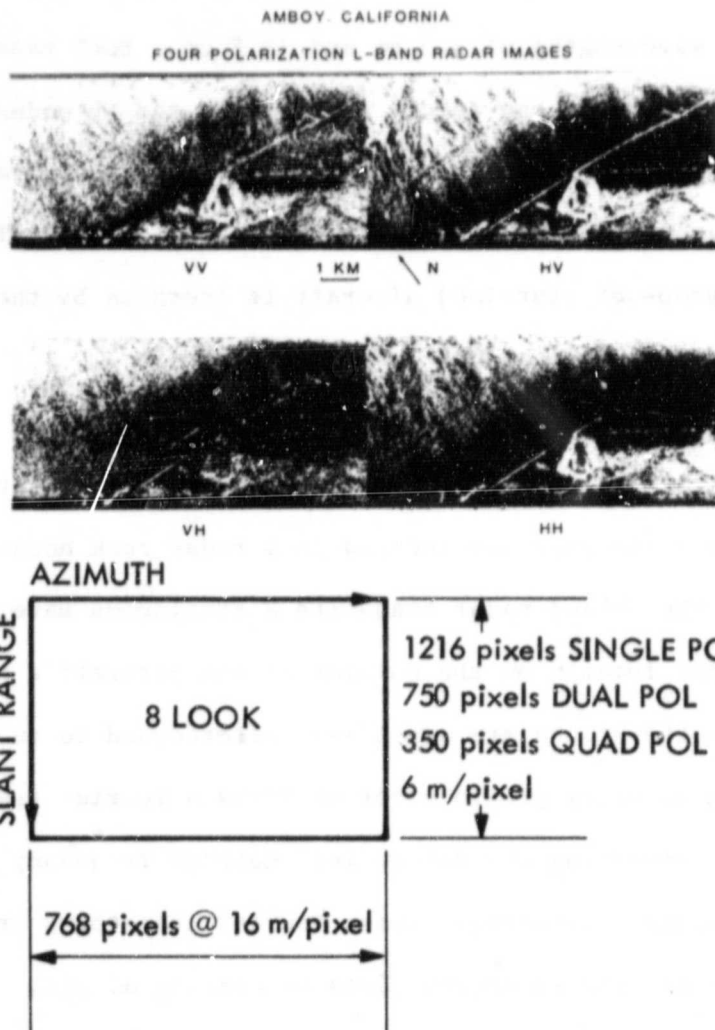


Figure 4. Digital SAR Image Format. Note that image size depends upon recording modes (which are described in greater detail in the Technical Data Sheets.)

SECTION III

THE NASA/JPL L-BAND and C-BAND SCATTEROMETER SYSTEMS

The NASA L-band and C-band scatterometers are two independent radars that operate at radar wavelengths of 6.3 cm and 18.8 cm. Both radars have polarization diversity and can record HH, VV, HV, and VH modes of angles of incidence between 5° and 60° . These radars are normally operated on the NASA/ARC C-130 research aircraft shown in Figure 5. This civilian version of a military four prop-jet (turbine) aircraft is operated by the NASA/ARC Medium Altitude Missions Branch.

A block diagram for these radar systems is shown in Figure 6. Most of the electronics and controls are located in a radar rack housed inside the C-130 aircraft. The C-band radar transmits a continuous wave (CW) signal via a stripline antenna located on the outside of the aircraft's rear ramp door. Radar echoes from the ground are amplified, heterodyned to an audio frequency, and digitized. A hardware preprocessor performs a Fourier transform on these samples, thereby separating the echoes into Doppler frequency bands equivalent to along-track angular filtering. These Fourier transforms are recorded on an onboard tape recorder for subsequent data processing at JPL. A similar system is used for the L-band scatterometer, except that the antenna system is in a radome underneath the C-130 tail. Tab. 2 lists the SCAT operating parameters.



Figure 5. The NASA/ARC C-130 Research Aircraft. This aircraft is operated by the ARC Medium Altitude Missions Branch. The antennas for the SCAT systems are located just underneath the tail in the aft position of the aircraft.

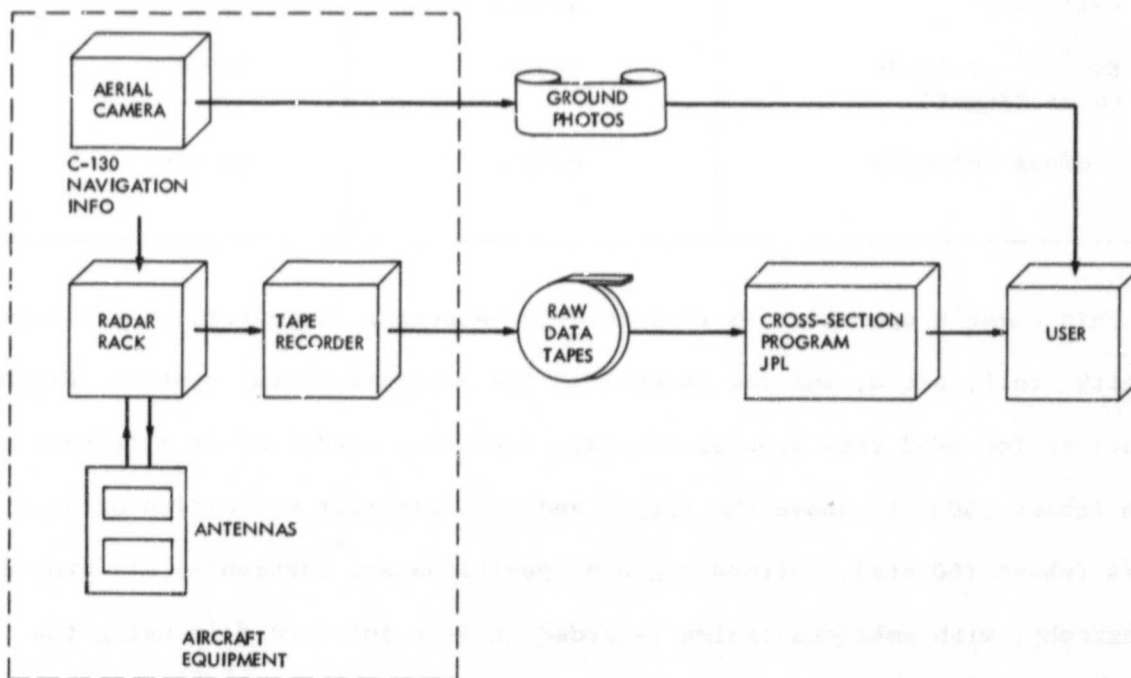


Figure 6. Block Diagram for SCAT Data Flow. Radar signals are Fourier-transformed onboard the aircraft. Postflight data reductions will reduce these to ground radar cross sections.

Table 2. NASA/JPL L-band and C-band SCATs Radar Parameters

Parameter	L-band Value	C-band Value
Frequency	1.6 GHz	4.75 GHz
Wavelength	18.8 cm	6.3 cm
Spectral resolution	10 Hz	20 Hz
Transmitter output	1.0 W	0.1 W
Antenna gain	22 dB	18 dB
Antenna beamwidth	8° x 120°	2.5° x 30°
Incidence angle resolution	5°	5°
Incidence angle coverage	5° - 60°	5° - 60°
Cell size	40 m x 70 m	40 m x 20 m
Nominal altitude (over target)	500 m	500 m
Nominal velocity	80 m/s	80 m/s

This radar's operation is tied to C-130 aircraft parameters of altitude, velocity, roll, pitch, and yaw as well as the aircraft timing system. Flight operations for SCAT data acquisitions are typically conducted at altitudes of 500 m (about 1500 ft) above the target and with aircraft velocities of about 80 m/s (about 160 kts). Aircraft ground positions are documented via ground photography, with embedded timing recorded on 9-in infrared film using the C-130 Zeiss Camera.

This radar will be operated in one 10-flight, 3-week mission per year. (In FY84, this mission will be a SIR-B underflight mission.) A mission's first flight will normally be dedicated to an engineering checkout of the system. Subsequent flights will be dedicated to science data acquisition. During these flights, the scatterometers will be operated by JPL personnel. In all cases, a user or his designated alternate will participate in the flight operations. The user will be expected at Ames Research Center one or two days prior to his first flight and will be expected to stay with the aircraft for several days.

Following an aircraft mission, the SCAT data will be processed by JPL personnel. The primary output of this processing will be a time-ordered listing of sigma-nought versus angles of incidence, as shown in Figure 7. This will be available as both computer listings and computer-compatible tapes. A non-JPL user may wish to be at JPL when his data is being processed to provide quick-look analysis and support to processing personnel.

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SECTION IV

USER DUTIES

Users wishing to acquire NASA L-band SAR imagery and/or L- and C-band SCAT data need to perform the following steps:

1. The user must submit a Research Technology Operating Plan (RTOP) or proposal and Flight Requests to NASA at the appropriate time.
2. Once approved, the user should finalize flight paths about one month prior to his data flights. (This is needed to secure aircraft clearances as well as establish data acquisition strategies.)
3. The user or his alternate should participate in those flights in which radar data is being acquired for his program.
4. The user may possibly participate in data reduction operations at JPL.
5. The user will provide NASA with feedback on the quality and timeliness of his data.

Radar data flights can also be conducted by users funded by agencies other than NASA. In this case, the user should contact the Radar Program Manager at NASA Headquarters to discuss the proposed work. Questions of a programmatic nature should be addressed to the appropriate contact at NASA Headquarters. Questions pertaining to radar operations should be addressed to the JPL Aircraft Radar Manager. Questions pertaining to aircraft operations should be addressed to the appropriate contact at the ARC Medium Altitude Missions Branch. Telephone numbers and addresses are given in Technical Data Sheet 1.

The actual request for SAR and/or SCAT data is via RTOP or proposal (and accompanying Flight Request) submitted to NASA's Office of Space Science and Applications (OSSA). Both the RTOPs or proposals and the Flight Requests must identify the need for SAR and/or SCAT data. Approved requests for SAR and/or SCAT, and their Flight Requests, will then be collected by the JPL Aircraft Radar Manager in order to plan a data acquisition program. A plan for SAR and SCAT operations will be generated in conjunction with aircraft flight activity plans made by the ARC Airborne Missions and Applications Division and approved by NASA Headquarters.

After the RTOP and Flight Request approvals, a CV-990 or C-130 mission will be defined by the ARC Medium Altitude Missions Branch. These aircraft missions often carry other (nonradar) instruments under the direction of a Mission Manager named by the Medium Altitude Mission Branch. Flight lines should be fixed about one month in advance in order to obtain clearances. Flight lines are often specified on standard air charts maps with latitude and longitude for the beginning and end points for each flight line. At this point, the user should be familiar with the radar data recording options described in the Technical Data Sheets. The user will also participate in the flights. The user or his alternates will be expected to be at ARC a day or two before his first flight and stay with the aircraft for a few days.

Immediately following the flights, the SAR or SCAT data will be processed at JPL. The user may wish to visit JPL to provide advice in data processing. Following the receipt of radar data, users are expected to provide feedback on the quality of their data using the form shown in Technical Data Sheet 4.

This will provide NASA with information to improve this program. Publication of reports or journal articles would be expected in 1 or 2 years following the flights. If a non-JPL user publishes in the open literature, then the following citation in an acknowledgement would be expected:

"Radar data was provided courtesy of the Jet Propulsion Laboratory, California Institute of Technology."

APPENDIX

TECHNICAL DATA SHEET 1: ADDRESSES AND PHONE NUMBERS

NASA Radar Program Manager

Richard Monson
Code EL-4
NASA Headquarters
Washington, D.C. 20546
(202) 755-8573

ARC Medium Altitude Missions

R. Cameron
J. Reller, Jr. (CV-990)
R. Mason (C-130)
Medium Altitude Missions Branch
Mail Stop 211-12
NASA/Ames Research Center
Moffett Field, CA 94035
(415) 965-5336 (FTS 448-5336)

JPL Aircraft Radar Manager

Thomas W. Thompson*
(213) 354-3792 (desk)
(213) 354-2654 (messages)

JPL Aircraft Operations

Elmer McMillan*
(213) 354-4870

JPL SAR Optical and Digital Correlator

Thomas Andersen*
(213) 354-3964

JPL Radar Librarian

Donald Harrison*
(213) 354-2386

*Jet Propulsion Laboratory
Mail Stop 183-701
4800 Oak Grove Drive
Pasadena, CA 91109

TECHNICAL DATA SHEET 2: SAR OPERATIONS CONSIDERATIONS

SAR operations are discussed here in three main topics: (1) optical recording options, (2) digital recording options, and (3) coverage and resolution considerations.

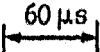
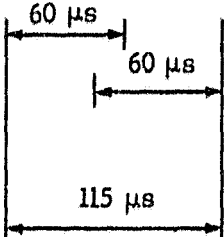
Optical Recording Options

The optical output of the L-band SAR is exposed signal film which records radar echoes from individual pulses. There are two optical recorders, each having two data channels; thus there are four possible channels of data acquisition.

There are three basic optical recording modes, as shown in Table 3. In the "QUAD POL" mode, the four data swaths are dedicated to the VV, HH, HV, and VH modes, respectively. Each swath records 60 μ s of data. All four QUAD POL data recorders start and end at the same time.

An alternative recording mode is the "EXTENDED SWATH" mode, in which two 60- μ s swaths overlap by 5 μ s. This provides 115 μ s of data acquisition. The "HORIZONTAL EXTENDED SWATH" mode, which records HH and HV data, and the "VERTICAL EXTENDED SWATH" mode, which records VV and VH data, are two more alternate recording modes. Basically, the choice between the QUAD POL and EXTENDED SWATH modes is one between full polarization diversity with a 60- μ s swath and partial polarization diversity with a 115- μ s swath. This is discussed later in this Technical Data Sheet.

Table 3. SAR Optical Recorder Options

Recording Mode	Recorder 1		Recorder 2		Range Coverage
	Chan A	Chan B	Chan A	Chan B	
QUAD POL	VV	HH	HV	VH	
HORIZONTAL EXTENDED SWATH	HV	HH	HV	HH	
VERTICAL EXTENDED SWATH	VV	VH	VV	VH	

H* = Transmit horizontal (\vec{E} parallel to A/C velocity \vec{V})

*H = Receive horizontal (\vec{E} parallel to A/C velocity \vec{V})

V* = Transmit vertical (\vec{E} perpendicular to A/C velocity \vec{V})

*V = Receive vertical (\vec{E} perpendicular to A/C velocity \vec{V})

The along-track recording rates are synchronized to the aircraft velocity, thus providing a uniform optical processing format. Raw signal film is recorded at a rate of 10 mm/s at an aircraft velocity of 500 kts. There is some 63 m (190 ft) available in each roll; this provides for about 1500 km (about 800 nautical miles) of along-track coverage per roll of film. Some 90 minutes of data recording fills a film.

Digital Recording Options

An alternate method to the optical recording mode is to record SAR data with a high-speed digital tape recorder. The digital data is normally used for more quantitative analysis of the SAR data.

The digital recording mode commences with the collection of 8192 x 6 bit samples of the video radar output for every radar pulse. The samples are collected at a rate of 50 megasamples/s. Thus the samples are separated by 20 ns. In the SINGLE POL mode, all 8192 samples are dedicated to a single signal (i.e., to a single polarization). In the DUAL POL and QUAD POL modes, these 8192 samples are divided equally between two polarizations for each pulse. In the QUAD POL modes, the radar's pulse repetition frequency (PRF) is doubled, and horizontal and vertical polarizations are transmitted on alternate pulses. These 8192 samples are stored in a memory and then transferred to a high-density digital tape (HDDT).

A primary consideration in deriving data acquisition rates for digital recordings is the fact that the tape drives are running at a constant speed while the radar PRF will vary depending upon the aircraft's velocity. The tapes, which are driven at 60 ips and 120 ips, have 12 tracks. The resulting data transfer rates are 3.340 megasamples/s at 60 ips and 6.680 megasamples/s at 120 ips (each sample is 6 bits). The radar PRF is tied to aircraft velocity to facilitate the optical processing. Thus the PRF is twice the aircraft velocity in knots for the SINGLE POL and DUAL POL modes, and is four times the aircraft's velocity in the QUAD POL modes. At a nominal aircraft velocity of

500 kts, the radar PRFs are 1000 Hz and 2000 Hz, respectively. At normal aircraft altitudes, the aircraft's velocity varies between 400 and 600 kts. Thus the PRFs for SINGLE POL and DUAL POL modes can vary between 800 and 1200 Hz. The PRFs for the QUAD POL modes can vary from 1600 to 2400 Hz. The total number of samples that can be transferred on a single pulse is simply the data rates of 3340 or 6680 kilosamples/s divided by the PRF in kHz.

Another consideration in deriving digital data rates is the fact that each pulse transfer has a 192-bit (32-sample) header. The leading 24 bits of this header is a pseudo-random positive-negative (p-n) sequence used as a timing marker later in the data reduction. The remaining bits of the header contain navigational information.

Another consideration is total recording time. This is the total tape length (9200 ft) divided by the recording rates of 60 ips or 120 ips. Thus total record times are 30 minutes and 40 seconds at 60 ips, and 15 minutes and 20 seconds at 120 ips.

All of these considerations are summarized in Table 4. It should be noted that the data swaths vary widely depending upon the aircraft velocity, the recording mode, and the basic tape speed. The implications of these differences in data swath coverage are described in the next section of this Technical Data Sheet.

Table 4. SAR Digital Recorder Options

Radar Mode	SINGLE POL DUAL POL			QUAD POL		
Aircraft velocity	400 kts	500 kts	600 kts	400 kts	500 kts	600 kts
Radar PRF	800 Hz	1000 Hz	1200 Hz	1600 Hz	2000 Hz	2400 Hz
Data transfer rate @ 60 ips	3340 kilosamples/s					
Total record time @ 60 ips	30 minutes and 40 seconds					
Data swath @ 60 ips	83 μ s	66 μ s	55 μ s	41 μ s	33 μ s	27 μ s
Total distance @ 60 ips	360 km 100 nmi	460 km 250 nmi	560 km 300 nmi	360 km 200 nmi	460 km 250 nmi	560 km 300 nmi
Data transfer rate @ 120 ips	6680 kilosamples/s					
Total record time @ 120 ips	15 minutes and 20 seconds					
Data swath @ 120 ips	163 μ s	133 μ s	111 μ s	83 μ s	66 μ s	55 μ s
Total distance @ 120 ips	180 km 100 nmi	230 km 125 nmi	280 km 150 nmi	180 km 100 nmi	230 km 125 nmi	280 km 150 nmi

Coverage and Resolution Considerations

This section of the SAR Technical Data Sheet describes two important aspects of SAR data acquisition: ground coverage and resolution. Synthetic aperture radars acquire data as shown in Figure 8. Ground features are located in two coordinates, slant range and azimuth. Slant range is simply the distance between the airborne radar and the target when the aircraft is abeam of the target. (Slant range is often given in the equivalent time delay to the target.) Azimuth is the distance of the target as measured parallel to the aircraft velocity vector or as measured parallel to the aircraft's ground track.

Since most surface features are located primarily by distances measured along the ground, the radar measurement of slant range must be converted to a ground range. The geometry shown in Figure 8 indicates that ground range is given by:

$$R_g = [(c/2 (D_o + \Delta d))^2 - H^2]^{1/2} \quad (2.1)$$

where R_g = ground range
 c = speed of light
 D_o = time delay to start of data
 $D_o + \Delta d$ = time delay to the target
 H = aircraft altitude above the ground

For convenience, the time delay to the start of data is set at 5 μ s before nadir echoes (i.e., $[c/2] [D_o + 5 \mu s] = H$).

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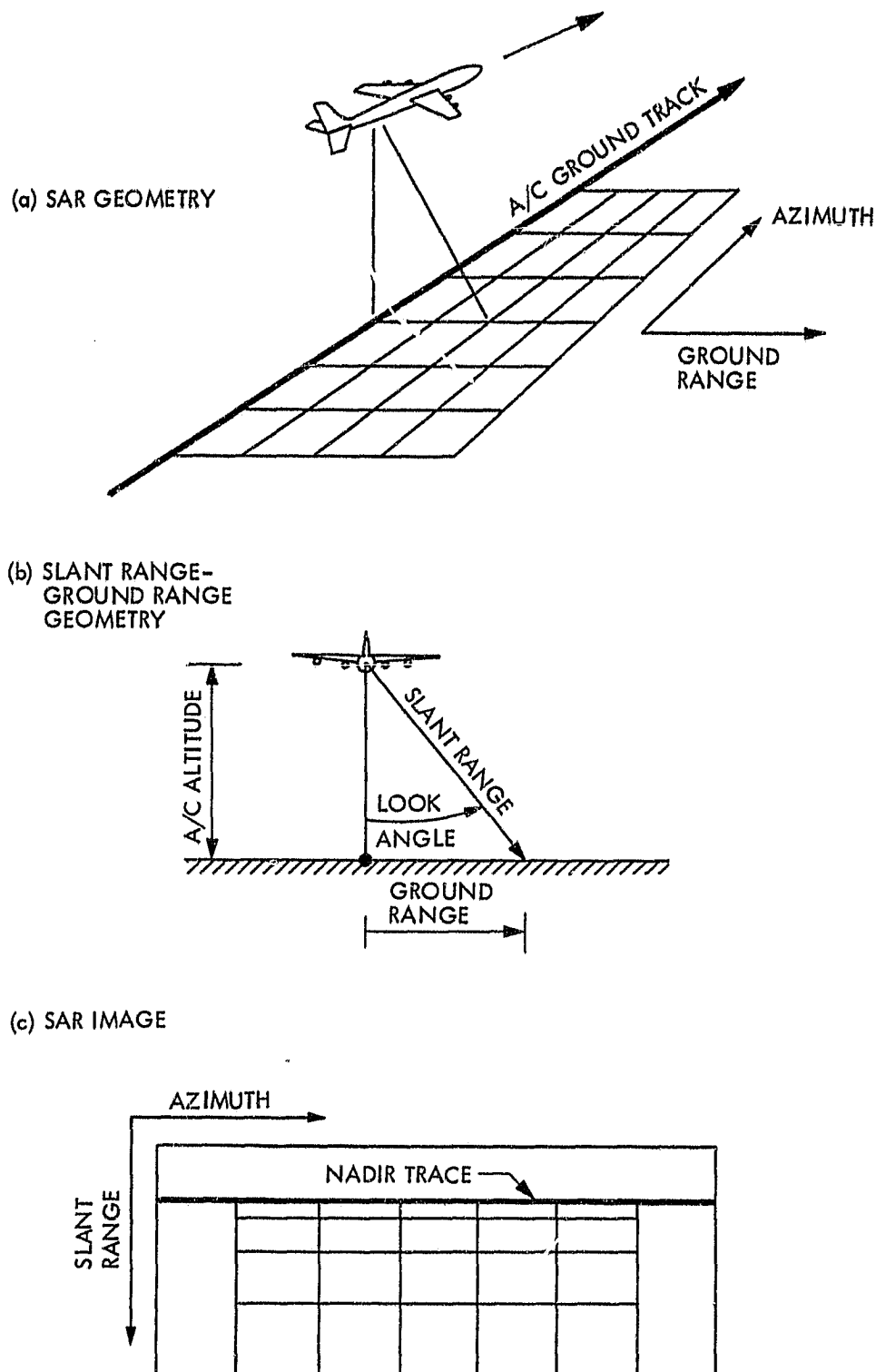


Figure 8. SAR Image Geometry. Note that a square grid on the ground is compressed in one dimension in the SAR image. This is illustrated in part by the optical image shown in Figure 3.

Another important radar parameter is θ_i , the angle of incidence for the radar beam. This is given by:

$$\theta_i = \arctan (R_g/H) \quad (2.2)$$

Table 5 gives ground range versus time delay. Optical recording modes have data swaths of 60 or 115 μ s, which yield cross-track coverages of about 15 and 22 km. Digital recording modes at 60 ips have data swaths of 33 and 66 μ s at nominal aircraft velocities, which yield data swaths of about 8, 16, and 26 km, respectively.

The ground resolution in the cross-track direction is the slant range resolution divided by the sine of the incidence angle, i.e.:

$$r_s = \text{slant range resolution} = c/2B \quad (2.3)$$

$$r_g = \text{ground range resolution} = c/(2B \cdot \sin \theta_i) \quad (2.4)$$

where $c/2$ = radar velocity = 150 m/ μ s

B = radar bandwidth = 18 MHz (digital)
15 MHz (optical)

θ_i = angle of incidence = 20° to 60°

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Table 5. Ground Range and Angle of Incidence Versus Relative Delay

Relative Delay	Ground Range (km)				Angle of Incidence			
5 μ s	0.0	0.0	0.0	0.0	0°	0°	0°	0°
10 μ s	2.3	3.1	3.8	4.3	37°	27°	23°	20°
20 μ s	4.3	5.7	6.8	7.7	55°	43°	37°	33°
30 μ s	6.0	7.7	9.0	10.2	64°	52°	45°	40°
40 μ s	7.7	9.5	11.0	12.4	69°	58°	51°	46°
50 μ s	9.3	11.3	12.9	14.4	72°	62°	55°	50°
60 μ s	10.8	12.9	14.7	16.3	75°	65°	59°	54°
70 μ s	12.4	14.6	16.4	18.1	76°	68°	61°	57°
80 μ s	13.9	16.2	18.1	19.9	78°	70°	64°	59°
90 μ s	15.5	17.8	19.8	21.6	79°	71°	66°	61°
100 μ s	17.0	19.3	21.4	23.3	80°	73°	67°	63°
110 μ s	18.5	20.9	23.1	25.0	81°	74°	69°	64°
120 μ s	20.0	22.5	24.7	26.7	81°	75°	70°	66°
130 μ s	21.5	24.0	26.3	28.3	82°	76°	71°	67°
140 μ s	23.1	25.6	27.8	29.9	83°	77°	72°	68°
150 μ s	24.6	27.1	29.4	31.5	83°	78°	73°	69°
Altitude Above Target	3 km 10,000 ft	6 km 20,000 ft	9 km 30,000 ft	12 km 40,000 ft	3 km 10,000 ft	6 km 20,000 ft	9 km 30,000 ft	12 km 40,000 ft

Two bandwidths are considered, since the recording on film blurs the higher frequencies, resulting in an effective bandwidth of about 15 MHz. Thus slant range resolutions are 8.33 m and 10.0 m, respectively. Two angles of incidence, 20° and 60° , are also considered, since they are reasonable lower and upper limits for SAR coverage. The resulting digital and optical ground range resolutions are 24.4 m and 29.2 m at 20° angle of incidence, and 9.6 m and 11.6 m at 60° angle of incidence.

Azimuth resolution, the ability to resolve features in the along-track direction, depends upon a number of factors. The NASA/JPL L-band SAR has an azimuth resolution of about 10 m.

TECHNICAL DATA SHEET 3: SCAT OPERATIONS AND RECORDING OPTIONS

The L- and C-band SCATs operate by transmitting a CW signal at the ground and recording the Fourier transforms of the echoes on a digital tape. Sometime after a flight, this data will be processed to obtain terrain radar scattering behavior in terms of the normalized radar cross section, σ^0 , versus a range of angles of incidence, θ .

During the flight, the received power is recorded as a power spectrum. The ground is illuminated by a fan beam and the various angles of incidence are directly related to Doppler frequencies. In particular:

$$f_d = (2V/\lambda) \sin(\theta_i) \quad (3.1)$$

where f_d = observed Doppler Shift

V = aircraft velocity

λ = radar wavelength

θ_i = angle of incidence

The scattering area has a footprint, which is a parallelogram aligned with the aircraft's ground track. Thus the scattering area is the product of the width (cross track) and a length (along track) of this footprint. The length of the scattering areas is determined by Doppler filtering of the echo. Thus:

$$L = R\Delta\theta_i = \frac{H\Delta\theta_i}{\cos(\theta_i)} = \frac{H\Delta f \lambda}{2V \cos^2(\theta_i)} \quad (3.2)$$

where L = scattering area length (along track)

k = range

H = aircraft altitude above the ground

Δf = spectral resolution

The width (cross-track dimension) of the footprint is determined by antenna bandwidth, thus:

$$W = R\Omega = \frac{HB}{\cos(\theta_1)} \quad (3.3)$$

where W = scattering area length (along track)

Ω = antenna beamwidth

Nominal aircraft parameters are:

$$H = 500 \text{ m} \approx 1500 \text{ ft}$$

$$V = 80 \text{ m/s} \approx 160 \text{ kts}$$

$$f_L = 1.6 \text{ GHz}, \lambda_L = 18.8 \text{ cm}$$

$$f_c = 4.75 \text{ GHz}, \lambda_c = 6.3 \text{ cm}$$

$$\Omega_L = 10^\circ$$

$$\Omega_c = 3^\circ$$

$$\Delta f_L = 10 \text{ Hz}$$

$$\Delta f_c = 20 \text{ Hz}$$

The SCAT footprint sizes for these nominal parameters are given in Table 6.

Table 6. SCAT Parameters and Footprint Sizes

Angle of Incidence	L-band		C-band	
	Along Track	Cross Track	Along Track	Cross Track
10°	6 m	x 87 m	4 m	x 27 m
20°	7 m	x 93 m	5 m	x 28 m
36°	9 m	x 101 m	6 m	x 30 m
40°	13 m	x 114 m	9 m	x 34 m
50°	22 m	x 136 m	15 m	x 41 m
60°	47 m	x 175 m	32 m	x 52 m
Wavelength	18.8 cm		6.3 cm	
Antenna beam width	10°		3°	
Doppler resolution	10 Hz		20 Hz	
Aircraft height ≈ 500 m ≈ 1500 ft				
Aircraft velocity ≈ 80 m/s ≈ 160 kts				

TECHNICAL DATA SHEET 4:

FLIGHT REQUEST
AND
USER FEEDBACK FORMS

NASA/JPL SAR/SCAT USER COMMENT SHEET

We would like to determine what difficulties, if any, users of NASA/JPL Aircraft Radar Data are experiencing in acquiring data from these sensors. To that end, we encourage you to provide us with comments by completing the form below. Please return this to the JPL Aircraft Radar Manager. With your help and suggestions we hope to improve aircraft radar operations to better satisfy the needs of users.

These comments apply to the _____ Program Mo _____ Yr _____

Adequacy of mission flight lines and radar operations for the objectives of your program:

Data quality and timeliness:

Plans for data publication:

Return to:
T. W. Thompson
JPL Aircraft Radar Manager
Mail Stop 183-701
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109

Signed: _____

Phone #: _____

FLIGHT REQUEST		LOG NO.
AIRBORNE INSTRUMENTATION RESEARCH PROGRAM		FY
National Aeronautics and Space Administration		
PART I ORGANIZATIONAL DATA		
INVESTIGATION TITLE:		
PRINCIPAL INVESTIGATOR NAME: ORGANIZATION: AGENCY/CODE: ADDRESS: STATE, ZIP: PHONE:	FUNDING AGENCY SPONSOR (FOR NASA PROGRAMS LISTS NASA HQ SPONSOR) NAME: ORGANIZATION: AGENCY/CODE: ADDRESS: STATE, ZIP: PHONE:	
SIGNATURE: _____ DATE: _____		
PART II REQUIREMENTS SUMMARY		
(Brief summary of test sites, flight dates, flight support needs)		
PART III RATIONALE FOR USE OF NASA FACILITIES (Non-NASA Investigators)		
(State reason for requesting NASA support instead of contracting with private industry.)		
QUESTIONS REGARDING AIRCRAFT SUPPORT AND COMPLETED FORMS SHOULD BE DIRECTED TO: AMES RESEARCH CENTER NATIONAL AERONAUTICS AND SPACE ADMINISTRATION ATTN: AIRCRAFT PROGRAMS, MS 240-5 MOFFETT FIELD, CA 94035 TELEPHONE (415) 965-6099 FTS 448-6099	FOR A/C PROGRAMS USE ONLY <input type="checkbox"/> OSSA ORG CODE: _____ <input type="checkbox"/> NON-OSSA ORG. CODE: _____ <input type="checkbox"/> NON-NASA: FUNDING AGENCY: _____ <input type="checkbox"/> REIMB COST: _____ <input type="checkbox"/> PLAN <input type="checkbox"/> POST PLAN SENSOR: _____ A/C: _____ FLTS: _____ HRS: _____ A/C: _____ FLTS: _____ HRS: _____	

(Revised 1/83) Previous Editions are Obsolete

SE-7

PART IV BACKGROUND AND OBJECTIVES

A. NUMBER AND TITLE OF NASA RTOP, PROJECT PLAN, GRANT OR OTHER PROGRAM DOCUMENTATION WHICH THIS FLIGHT REQUEST SUPPORTS:
(Attach copy of appropriate documentation.)

B. PROGRAM OBJECTIVES: (Briefly describe the background and overall goals of the program which this flight request supports.)

CHECK ONE OR MORE DISCIPLINE OR APPLICATION CATEGORY:

- | | | |
|--|---|---------------------------------------|
| <input type="checkbox"/> AGRICULTURE | <input type="checkbox"/> OCEANOGRAPHY | <input type="checkbox"/> STRATOSPHERE |
| <input type="checkbox"/> FORESTRY | <input type="checkbox"/> SEA/LAKE ICE | <input type="checkbox"/> STORMS |
| <input type="checkbox"/> RANGELAND | <input type="checkbox"/> HYDROLOGY | <input type="checkbox"/> AIR QUALITY |
| <input type="checkbox"/> WILDLANDS | <input type="checkbox"/> GEOLOGY | <input type="checkbox"/> LIFE SCIENCE |
| <input type="checkbox"/> LAND USE | <input type="checkbox"/> GEODYNAMICS | <input type="checkbox"/> ASTRONOMY |
| <input type="checkbox"/> SURFACE POLLUTION | <input type="checkbox"/> COMMUNICATIONS | <input type="checkbox"/> GEOPHYSICS |
| <input type="checkbox"/> URBAN | <input type="checkbox"/> METEOROLOGY | <input type="checkbox"/> OTHER: _____ |

C. RATIONALE FOR AIRCRAFT SUPPORT: (Briefly summarize aircraft performance requirements or identify specific aircraft requested and rationale for selection. Specify role of aircraft in this investigation.)

SUPPORTING ROLE OF DATA COLLECTED BY AIRCRAFT (Check one or more):

- | | |
|--|--|
| <input type="checkbox"/> SATELLITE SYSTEM DEVELOPMENT | <input type="checkbox"/> TECHNOLOGY APPLICATIONS |
| <input type="checkbox"/> SATELLITE DATA INTERPRETATION | <input type="checkbox"/> SCIENTIFIC DATA COLLECTION |
| <input type="checkbox"/> SHUTTLE PAYLOAD DEVELOPMENT | <input type="checkbox"/> OPERATIONAL DATA COLLECTION |
| <input type="checkbox"/> COORD SPACECRAFT UNDERFLIGHT | <input type="checkbox"/> OTHER: _____ |

D. SPACECRAFT OR SENSOR DEVELOPMENT SUPPORTED BY THIS REQUEST:

E. THIS FLIGHT REQUEST IS:

- ☐ New Request ☐ Revision to new request ☐ Continuation or revision of old request

Request No. _____

Request No. _____

PART V SENSOR AND DATA REQUIREMENTS

A. **OBSERVATIONS:** (Describe the characteristics of the physical features to be observed and the phenomena to be measured. Specify the spectral regions of interest, spatial and spectral resolutions.)

B. **SENSORS:** (Identify the type of sensor or specific sensor required. Specify polarization, filtration, film type, etc. If this sensor is investigator supplied, specify integration requirements.)

C. **DATA:** (Specify data formats desired, housekeeping data requirements, sensor operation requirements, look angles, image overlap, data processing requirements, etc.)

PART VI SITE LOCATION AND FLIGHT SCHEDULE

A. **GEOGRAPHIC LOCATION:** (Attach map(s) showing flight requirements, or indicate regions of interest, key features, priorities, etc., and/or use PART VII worksheet to specify flight lines.)

B. **SCHEDULE:** (Indicate desired flight dates and tolerance for each observation.)

	FLIGHT SCHEDULE SUMMARY:						TOTAL DATA FLIGHTS:					
	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
AREA FLIGHTS	___	___	___	___	___	___	___	___	___	___	___	___
AREA FLIGHTS	___	___	___	___	___	___	___	___	___	___	___	___

C. **CONSTRAINTS:** (Specify desired weather conditions, cloud cover, sea-state, sun angle, tidal cycles, ground conditions, maximum and minimum altitude, etc., for each observation.)

PART VII FLIGHT REQUIREMENTS WORKSHEET

Complete a separate sheet for each test site.

TEST SITE				FLIGHT DATE AND TOLERANCE				
MEAN ALTITUDE ABOVE SEA LEVEL								
Flight Line Number	Flight Altitude	Flight Line Length In Nautical Miles	Time of Day of Flight (Local)	Flight Lines (Lat. & Long.)		Required Sensor (s)		
				Start	End			

COMMENT: